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ABSTRACT

The BL Lac objects MK501 and MK421 have been observed with OSO-8 and HEAO-1 X-ray detectors in the 2-60 keV band. Their spectra are similar with best fitting power laws having energy index $-.4 < \alpha < .4$. A soft X-ray excess is indicated in their spectra. There was no detectable X-ray absorption with implied column densities $N_H < 1.5 \times 10^{22}$ at/cm^2. MK421 was a factor 6 weaker in November 1977 than in May 1977. An identification of PKS0548-322 with a new source H0548-32 is suggested.

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I. INTRODUCTION

The recent 40" error box for MK501 (Schwartz et al. 1978) and the 1' error box of Marshall and Jernigan (1978) for MK421 confirms the existence of X-ray emitting BL Lac objects. Both of these objects were identified as BL Lac objects in the core of giant elliptical galaxies by Ulrich et al. (1975) and are the closest of the BL Lac objects with known redshifts (Stein, O'Dell and Strittmatter 1976).

II. OBSERVATION

MK421 was observed by the GSFC experiment on OSO-8 from days 138 to 140 1977. The A2 experiment* on HEAO-1 observed MK421 on days 324-331 of 1977, MK501 on days 231.5-241.5 and PKS0548-322 on days 256-265 of 1977. Both the HEAO and OSO-8 detectors are low background proportional counters sensitive over the range 2-60 keV. The OSO-8 data were taken in a pointed observation while the HEAO data were obtained during the all sky scan.

III. SPECTRA AND TIME VARIABILITY

The BL Lac X-ray spectra are remarkable for their hardness and lack of low energy absorption (Figures 1 and 2). The best fit to the MK421 data for a power law over the 2-30 keV range has a photon index $\alpha = .91$ (+.45, -.50), (90% confidence errors) and a column density $N_H < 8 \times 10^{21}$ at/cm^2. We note that the spectrum has a statistically significant soft X-ray excess for $E < 3.2$ keV, relative to the best fit. A thermal model does not have a well determined temperature and $kT > 30$ keV is required. For MK501 the best fit has $\alpha = 1.2$ (+.2, - .2) over the 2-30 keV range and $N_H \leq 1.8 \times 10^{22}$ at/cm^2; a thermal fit requires

*The A2 experiment on HEAO-1 is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL and UCB.

kT > 50 keV and is a poorer fit. We also see a soft X-ray excess in this spectrum. Because of the soft X-ray excess in these spectra the upper limits to absorption obtained by fitting single component power laws with absorption are somewhat misleading. In principle one could adjust the intensity and spectral shape of the low energy component to remove all evidence for absorption by cold material. It is only for large columns, $N_H > 5 \times 10^{22}$ at/cm^2, that the effect of absorption would be difficult to hide. The spectral index for both of these sources is identical, within errors, to the high frequency radio spectral index. MK421 has a 2-10 keV luminosity on days 138-140 of $\sim 5.3 \times 10^{-11}$ ergs/cm^2 sec while MK501 had a 2-15 keV luminosity of 8.9×10^{-11} ergs/cm^2 sec.

There is only slight evidence in our data for day to day variability in these sources with reduced $\chi^2_\nu = 1.74$ per degree of freedom for the OSO-8 observation and $\chi^2_\nu = 1.28$ per degree of freedom for the HEAO observation for the hypothesis of a constant source.

Comparison of the HEAO-1 and OSO-8 fluxes for MK421 show a factor 6 decrease from May till Nov. 1977. Our HEAO detection in Nov. 1977 was $\sim 7.9 \times 10^{-12}$ ergs/cm^2 sec in the 2-10 keV band $\pm 20\%$. This confirms the strong variability of this source in the X-ray band.

IV. OTHER BL LAC OBJECTS

For the BL Lac objects in the list of Stein et al. in our data base we can set a 2-10 keV upper limit of 2.4×10^{-11} ergs/cm^2 sec with the exception of PKS0548-322 which is detected at 3.6×10^{-11} ergs/cm^2/sec (Fig. 3). This source is near 4U0531-31. For some of these objects there is a hint of X-ray emission at a level 3-4 times below the upper limit quoted but

source confusion at this level prevents us from making a firm identification. The statistical weight of our detection of H0548-32 is $\sim 10\sigma$. The a priori probability of any of the ~30 BL Lac objects of Stein et al. falling in an error box of the size for H0548-32 (~.35 sq deg.) is $\sim 2.5 \times 10^{-4}$. Using the log N - log S relation derived by Warwick and Pye (1978) there is an a priori probability of $\sim 7 \times 10^{-4}$ of a random source of intensity $> 2.4 \times 10^{-11}$ ergs/cm^{2}sec lying in an error box of this size. At a level of $\sim 1 \times 10^{-11}$ ergs/cm^{2}sec we expect ~1 source per 10 resolution elements for the 3×3^0 field of view of HEAO A-2 and get a similar level of confusion at $\sim 8 \times 10^{-12}$ ergs/cm^{2}sec for our 3×1.5^0 field of view. The HEAO-1 A-2 experiment has also detected the N galaxy/BL Lac object 3C371 (Marshall et al. 1978) at a flux level of $\sim 1 \times 10^{-11}$ ergs/cm^2 sec in the 2-10 keV band.

V. DISCUSSION

PKS0548-322 is relatively close by with a $z \simeq .069$ (Fosbury and Disney 1976). The 2-10 X-ray luminosity, $L_X \simeq 6 \times 10^{44}$ ergs/sec* is similar to the optical luminosity of 3×10^{44} ergs/sec. For MK501 the X-ray and optical luminosity are 2.4×10^{44} and 3×10^{44} ergs/sec respectively. MK421 has an enormously variable X-ray luminosity ranging from 3×10^{43} to 3.2×10^{45} ergs/sec (Cooke et al. 1978) and an optical luminosity $\sim 6 \times 10^{44}$ ergs/sec. Thus for all 3 of these X-ray sources identification with a BL Lac object makes the X-ray emission of the same order or greater than the optical luminosity. This is similar to the situation in X-ray emitting Seyfert galaxies. If the X-ray spectrum continues with the same slope out to 100 keV the energy budget of these objects

*$H_0 = 50$ km/sec Mpc

is dominated by the X-ray emission.

The lack of a low energy X-ray turnover is consistent with a picture in which the nuclei of these objects are deficent in "cold" gas. Type 1 Seyferts often show X-ray column densities of $N_H \simeq 5 \times 10^{22}$ at/cm^2. The recently discovered class of X-ray emitting emission line galaxies typically have lower column densities, $N_H \lesssim 2 \times 10^{22}$ at/cm^2. Thus qualitatively speaking MK501 and MK421 have considerably less "cold" gas then type I Seyfert nuclei which may explain the lack of strong emission lines. The recent detection of these objects in soft X-rays (Hearn and Marshall 1978; Walter and Mason 1978) indicates column densities at least an order of magnitude lower than the limits quoted here.

The synchrotron self-Compton mechanism (SSC) (Jones, O'Dell and Stein 1974) is suggested as a source of the X-ray emission by the presence of a flat high frequency radio component and the similar slope of the X-ray and radio emission. Such analyses have been performed for MK421 by Margon, Jones and Wardle (1978) and for MK501 by Schwartz et al.

The combination of soft and hard X-ray observations show BL Lac objects to have a two component X-ray spectrum. Such a spectrum can be explained in a SSC model with the soft X-ray and U.V. flux being an extension of the optical synchrotron component while the hard X-rays are due to first order Compton scattering of the radio photons. Roughly speaking the soft X-rays should have power law with index $\sim 4/3$ steeper than the hard X-ray emission.

It is also possible that the steep soft X-ray component could be thermal in origin with $kT \sim 5 \times 10^6$K (Walter and Mason 1978). This component could in a sense account for the "missing gas" in BL Lac objects

vis a vis quasars and N galaxies. High energy resolution soft X-ray observations with HEAO-B will test this hypothesis.

If the SSC model is roughly correct then most compact extragalactic X-ray sources which do not have large column densities ($N_H < 2 \times 10^{22}$) should show soft X-ray excesses. An SSC model also makes definite predictions concerning the relationship of radio and X-ray flux which can only be tested by simultaneous observations. A program to test these predictions is now in progress.

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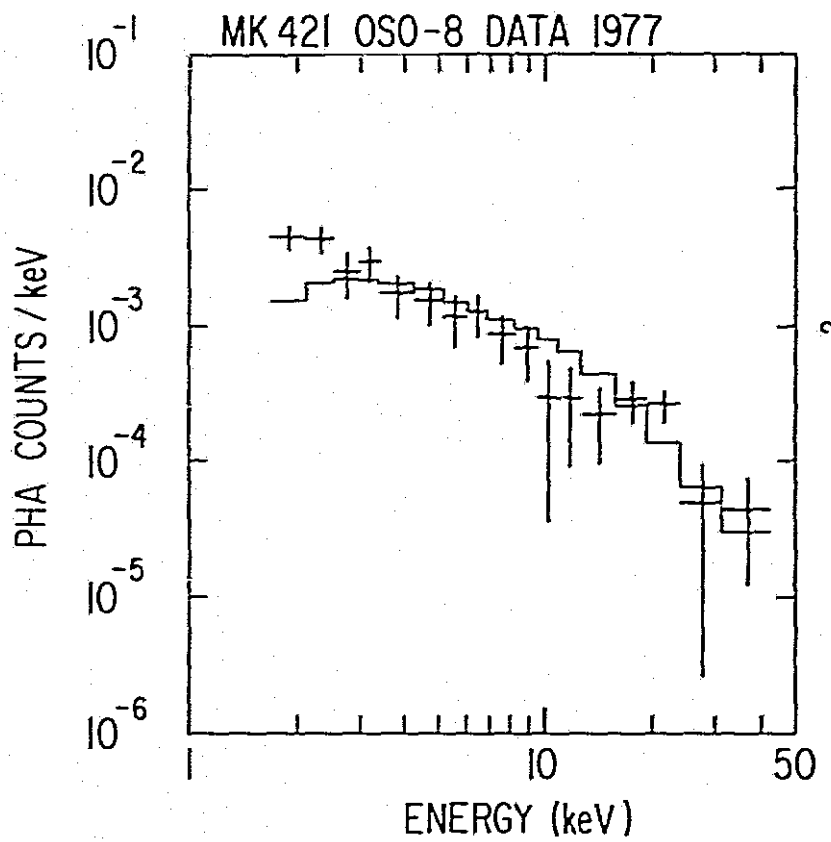
FIGURE CAPTIONS

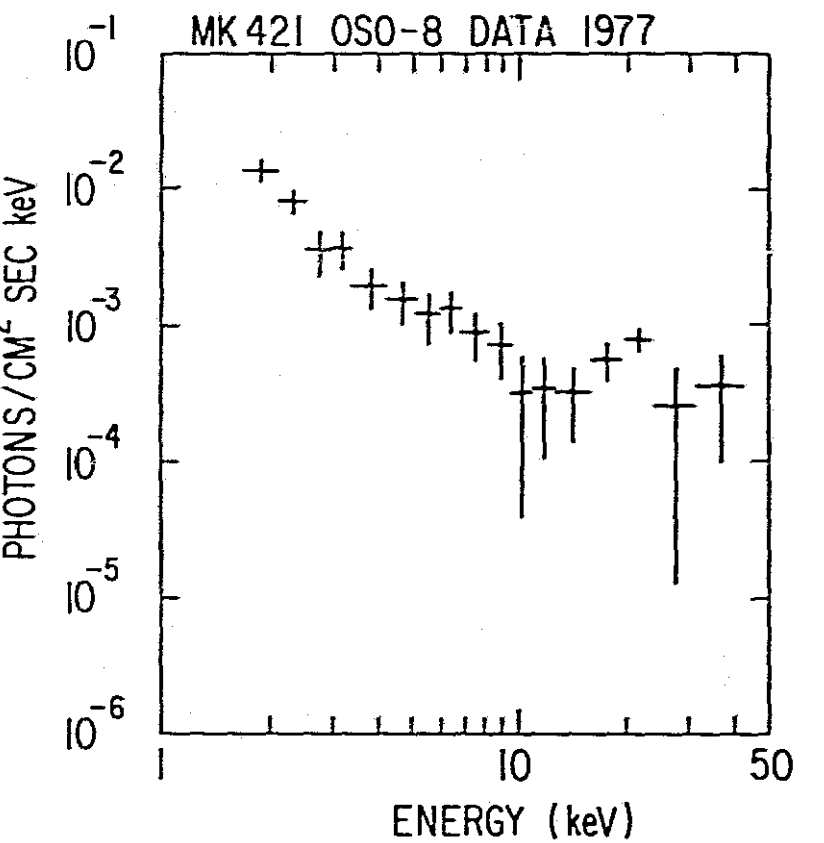
Figure 1a - Pulse height spectrum for MK421 with a power law fit of photon index $\alpha \sim 1.0$ indicated by the solid line. The crosses are the data points.

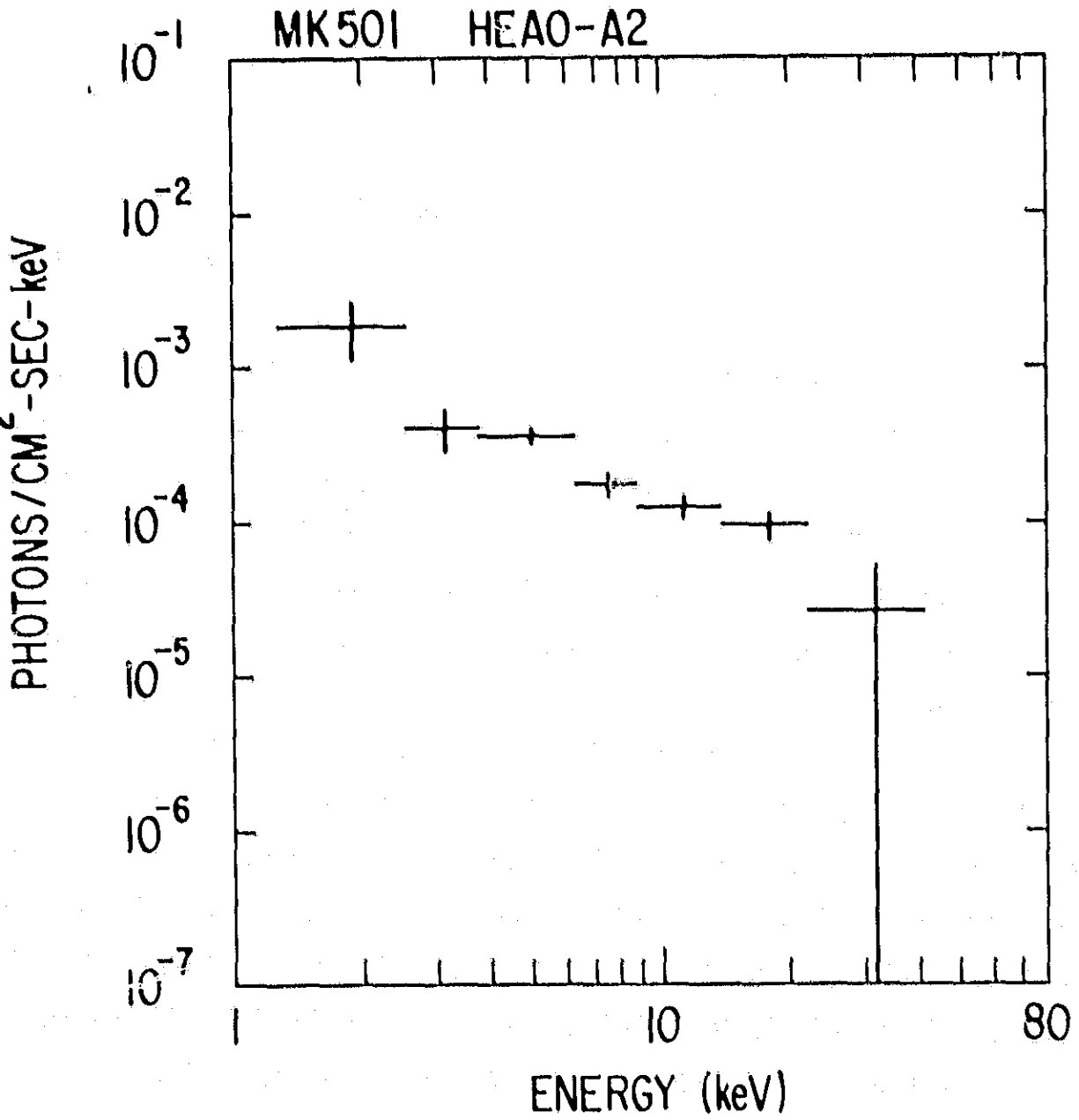
1b - The energy spectrum of MK421 unfolded using an $\alpha = 0$ spectral energy index. The fit has been performed from 3 to 30 keV for both MK421 and MK501.

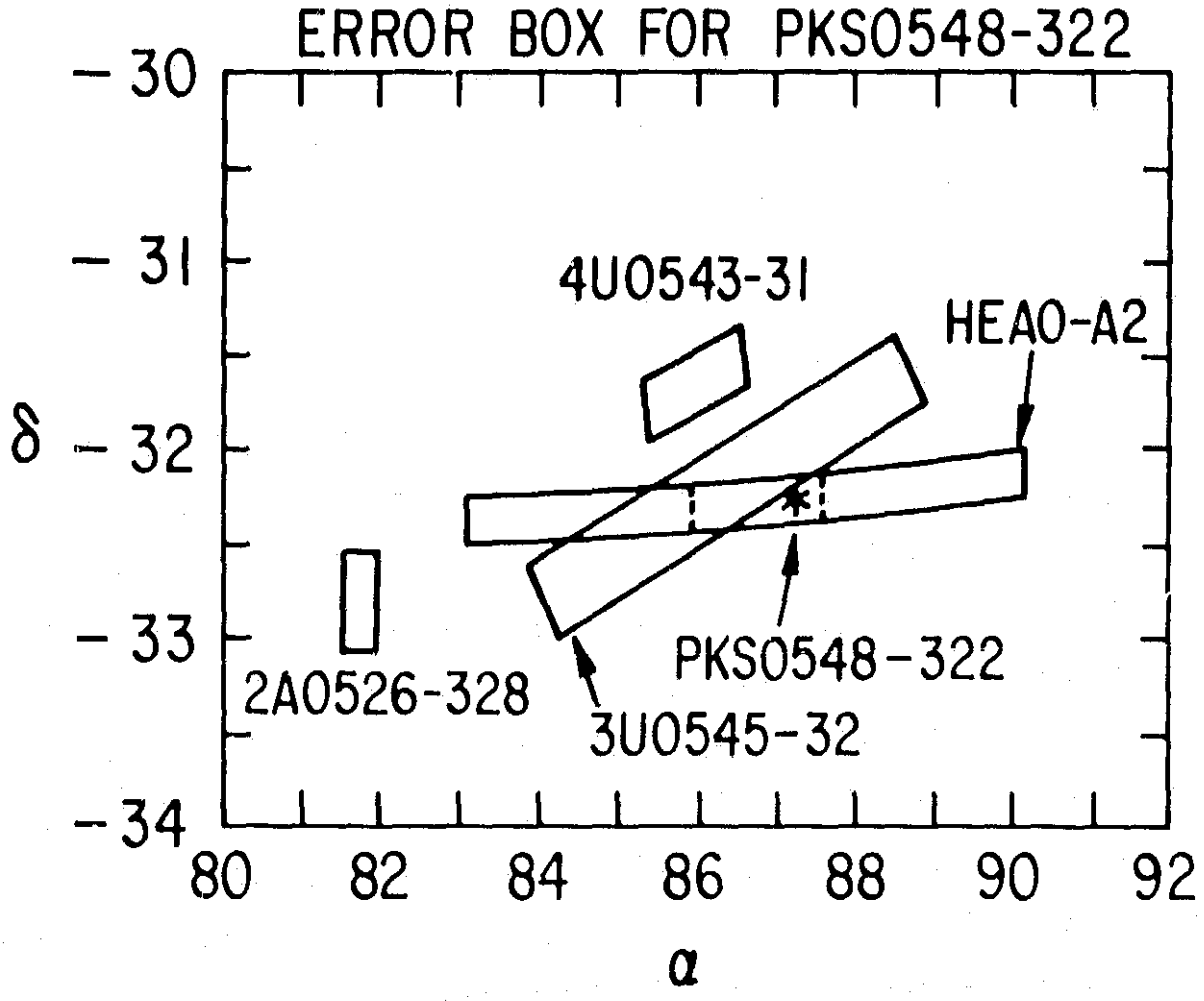
Figure 2 - The energy spectrum of MK501.

Figure 3 - HEAO X-ray error box for PKS0548-322. The dashed line represents the 90% confidence box in the direction orthogonal to the HEAO scan direction. We do not detect a source at the position of 4U0543-31; the source 2A0526-328 is detected but its HEAO error box has not been shown to reduce clutter in the diagram.


MK 421 OSO-8 DATA 1977
PHA COUNTS / keV
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
10
50
ENERGY (keV)


MK 421 OSO-8 DATA 1977
PHOTONS / CM^2 SEC keV
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
10
50
ENERGY (keV)


MK501 HEAO-A2
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
PHOTONS/CM^2-SEC-keV
1
10
80
ENERGY (keV)


ERROR BOX FOR PKS0548-322
-30
-31
-32
-33
-34
δ
80
82
84
86
88
90
92
α
4U0543-31
HEAO-A2
2A0526-328
PKS0548-322
3U0545-32

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16. Abstract

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